LOCOMOTIVES: LOwering CO2: Models to Optimize Train Infrastructure, Vehicles, and Energy Storage

Kickoff Meeting

Dr. Bob Ledoux
Program Director, ARPA-E

Goals of Kickoff Meeting

- Get to know each other – project overviews
- Stakeholder input
- Open source and IP information
- Common concerns
  - Methods for model validation
  - “universal” route data for cross model comparisons
  - ???

ARPA-E Team

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Program Director

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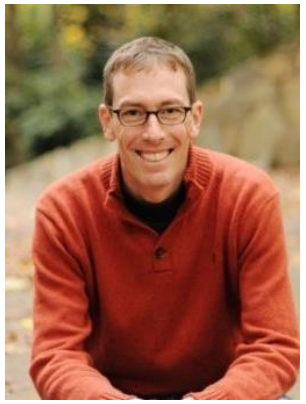

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Why Are We Here? Rail and Maritime Freight Decarbonization

One of the last bastions of fossil fuels?

How to Address Rail and Maritime Freight Decarbonization?

- Ultimate goal: decarbonize the rail and marine transport sectors.
- Proposed approach: focus on rail freight → successful technologies eventually implemented in marine sector
- Hypothesis: potential future program(s) government or private would fund research in ES and supporting infrastructure (e.g., charging / distribution). Co-optimization of ES and infrastructure likely needed
- LOCOMOTIVES focused on developing common analytical framework for all Class I rail on a route-by-route basis needed to set metrics, prioritize ES options, and allow relevant tech communities to understand/solve rail-domain-specific challenges/tradeoffs.

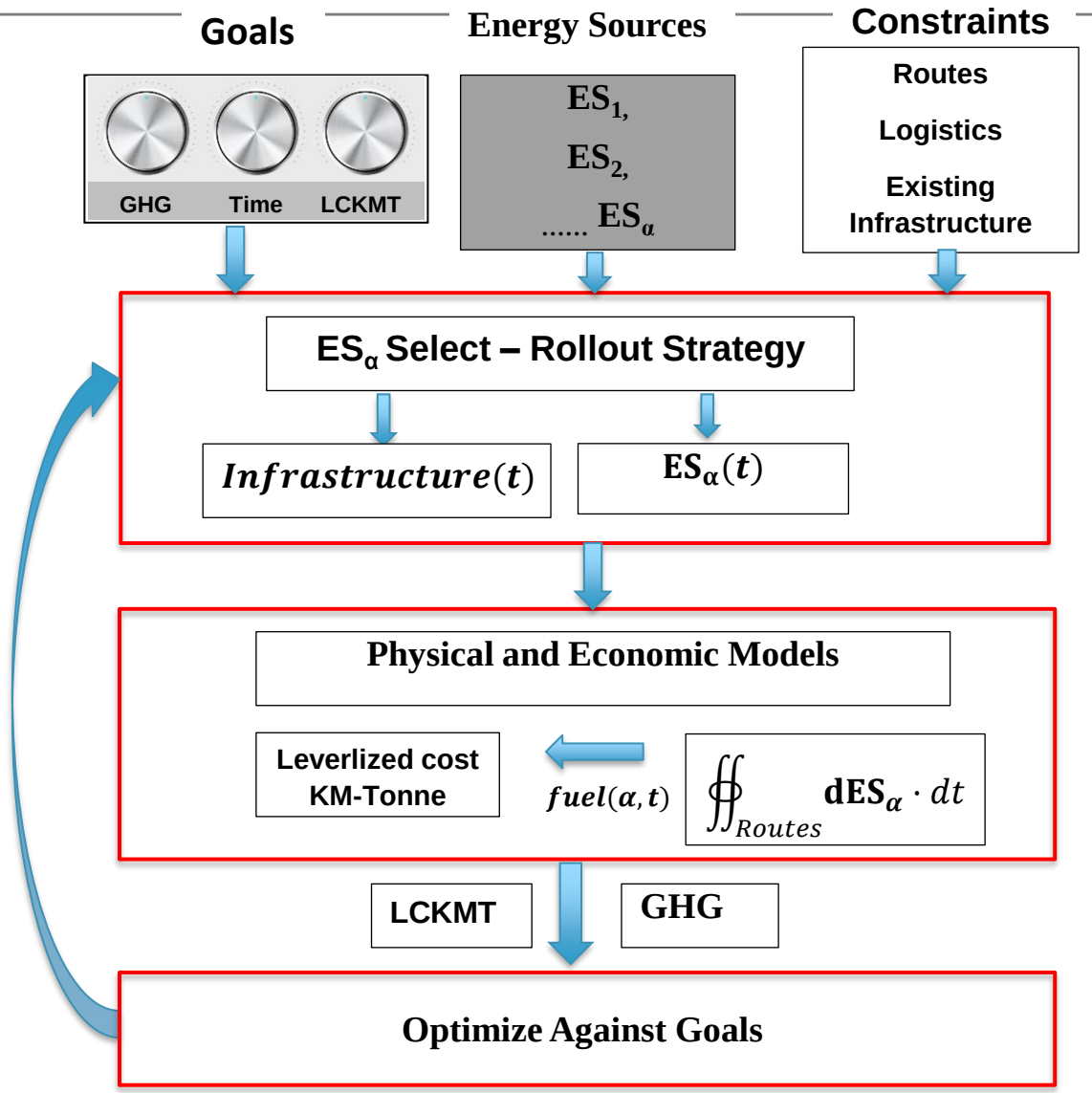
Challenges to Rail Decarbonization

- High power drive systems (≈ few MW “continuous”)
- Very high energy storage requirements (≈ 10-50 MWh)
- Need for widely distributed infrastructure
- Industry moving to larger trains
- High capital costs → long lifecycle for new technology
- Mostly privately owned → short term ROI

Rail Transportation Industry Operational Overview

- Fuel cost are a significant (10%) operational cost.
- Mass of power storage is not always dominant issue
- Emission reduction requirements have been partially mandated
- Already universally diesel-electric
- Safety is crucial
- Ports, rail yards have mature infrastructure – ISO rail cars, etc.
- Operating costs reduction drives investment in new technologies
- Technology adoption requires level playing field and interoperability between lines
- Serious risk aversion! 25 year lifetime of locomotives (3-5% turnover/year)
- All capital investments need to be “future proof”
- Need one or more technologies to hasten transition

LOCOMOTIVES : Proposed Model Structure



LOCOMOTIVES Goals

- Objective evaluation of cost/benefit of different ES.
- Provide open-source common analytical framework that sets baseline for improvement
- Stakeholders can try out “black box” ES + infrastructure options to see which work and how they are prioritized on a route-by-route basis
- Assist in evaluation of ES solutions – “level playing field”
- Identify optimal new technology deployment strategy
- De-risk capital investments

Potential New ES

- Batteries with regenerative braking
- Partial direct electrification – battery hybrid
- Fuel Cells, e.g., hydrogen
- Biofuels
- Hybrid
- (Improvements to bearings, wheels, aerodynamics?)

H2 R&D for Rail 2019

U.S. Department of Transportation

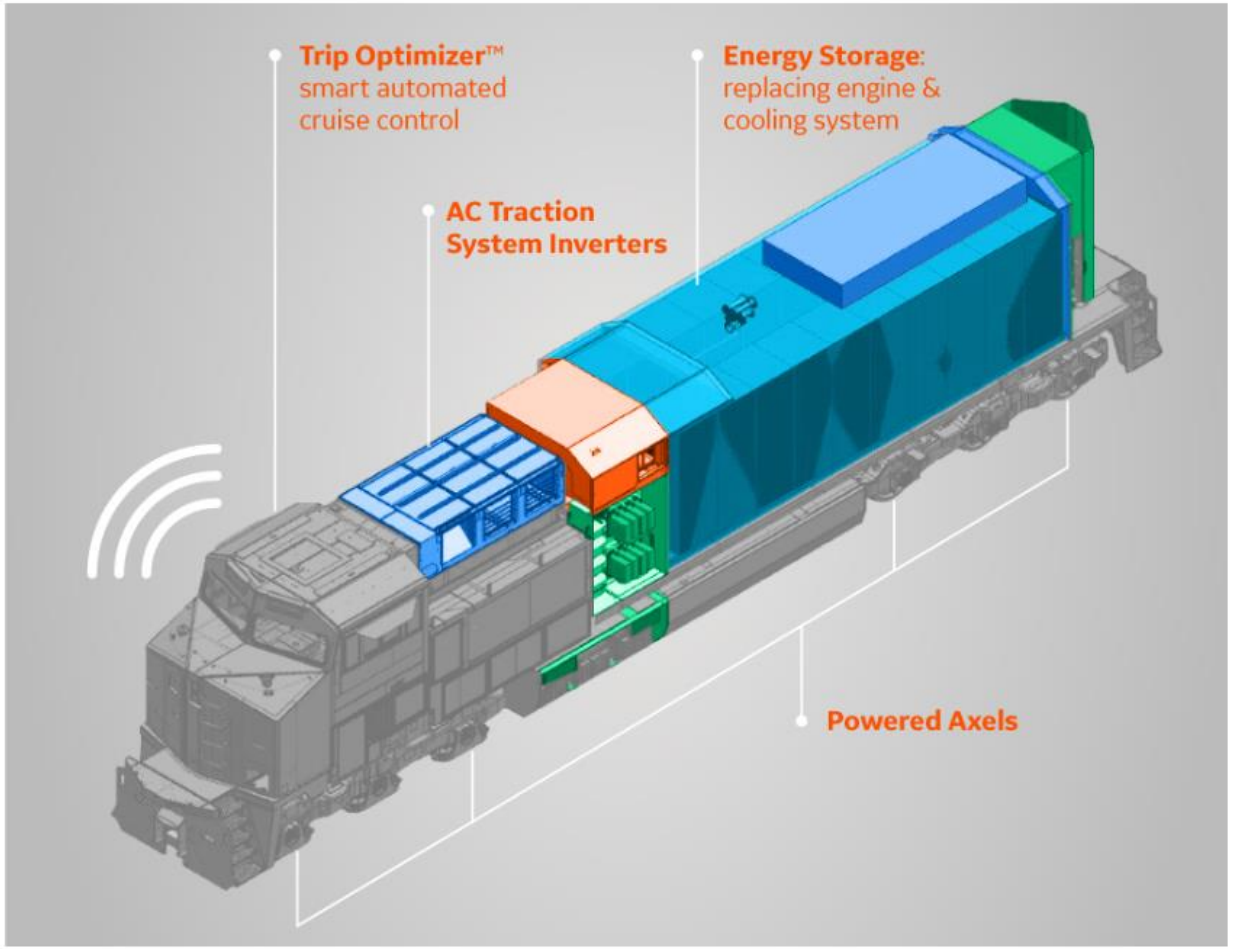
Federal Railroad Administration

Prototype Design and Evaluation of Hybrid Solid Oxide Fuel Cell Gas Turbine Systems for Use in Locomotives

H2@Rail[SM] Workshop

Workshop and report sponsored by the US Department of Energy Office of Energy Efficiency and Renewable Energy Fuel Cell Technologies Office, and the US Department of Transportation Federal Railroad Administration.

Wabtec Battery Powered Locomotive - 2021



Rail Tina: Bounding Models for ES

- Develop realistic train propulsion model
  - Incorporate important locomotive/train dynamics
  - Capable of extrapolation to any train configuration
  - Evaluates ES over all available routes, weather conditions, etc.
  - Outputs: power profile, fuel consumption, GHG, etc.
- LCKMT Models for static/simple ES rollout
  - Capital costs
  - Infrastructure costs
  - O&M (mostly fuel) costs

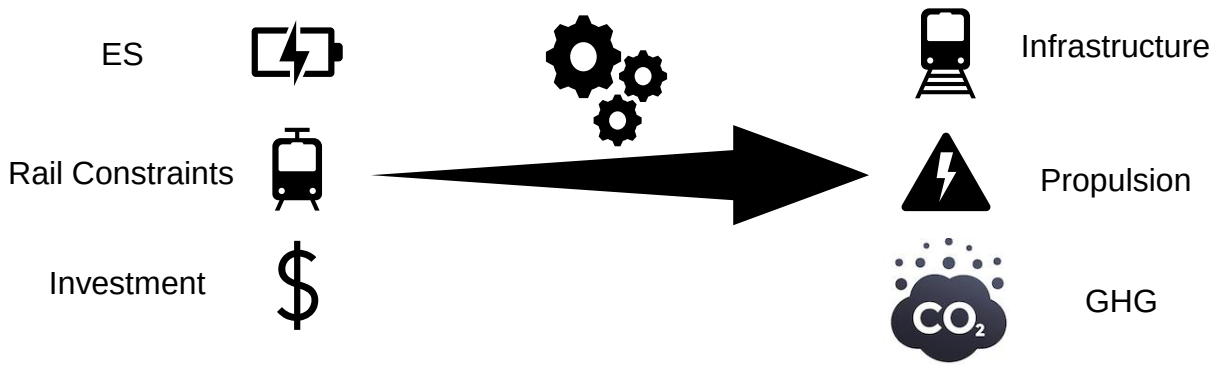
This program will be used to evaluate new ES on a level playing field with quantitative measures of GHG reductions and costs to implement and inform areas of greatest interest in a full program.

Model Inputs and Constraints

ES Technology	Rail Constraints	LCOTKM
Volumetric energy density	Locomotive type utilization	Discount rate/depreciation
Gravimetric energy density	Train specifications	$ ES capital
Specific Power (W/kg)	Rail car Specifications	$ ES infrastructure
Charge acceptance (max C-rate)	Regenerative Braking	$ fuel/TKm with geographical distribution
CO2/TKm	Route distribution	$ O&M – excluding fuel
$/kwh	Infrastructure distribution and characteristics (i.e. track type and condition)	$ logistical modification (e.g. Tender/car revenue loss)
$Capital deployed unit	Seasonal variations	$ cargo revenue
$Infrastructure deployed unit	Idle time	
$O&M	Freight and Passenger Demand	
CO2 production/life cycle	Weather constrains (i.e. air temperature and humidity)	
+$kwh regenerative	Stations (departure, terminal, intermediate)	
Reliability (% in service)	The maximum service capability of stations	
	Safety requirements (e.g. headway between successive dispatches and bottleneck problems on limited track capacity)	

Full Model Outputs

ES - Propulsion	Infrastructure	Potential Impact
Power delivered to wheels, P(t): - acc., + regen	Distance required between refuel for each ES	ES option chosen by route
Acceleration (t): + acc, - deacc	Time between refueling for each ES	% ES option chosen • On a per-route basis • On a per unit energy basis
Energy expended by ES(t), - delivered for propulsion, + regenerative	Fueling time	Lifecycle GHG +/- for each route vs baseline (today), based on chosen ES
Fuel(t) expended (same signage as ES(t)) for each propulsion source	Fuel quantity at each refueling	Cost (LCOTKM) +/- for each route vs baseline, based on chosen ES
GHG(t) for each source	Energy content for each refueling	Aggregate impact: lifecycle GHG and cost
	Cost for each refueling	Uncertainty quantification



New ES mix

GHG impact

LCKMT impact

Life after LOCOMOTIVES

- Open Source model extensions model to adjacent transportation sectors?
  - Short haul and passenger rail
  - Near shore and inland waterways
  - Intermodal port logistics

- Energy Systems R&D and infrastructure
  - Potential US government programs, DOT and DOE ?
  - RRs and RR industry
  - State and local priorities

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- What should we add?